PAVEMENT TECH NOTES

CONCRETE PAVEMENT PRESERVATION
DOWEL BAR RETROFITTING

Revised: September 27, 2002

GENERAL

Dowel bar retrofitting (DBR) is a Capital Preventive Maintenance (CapM) rehabilitation technique that is used to increase the load transfer capability of existing, in-service jointed plain concrete pavement (JPCP). Load transfer is the mechanism through which wheel loads are conveyed from one slab to the next through shear action (See Figure 1). It is an important consideration in the design of concrete pavements because the effective transfer of the wheel load from one slab to the next will significantly reduce the magnitude of the stresses and deflections at the

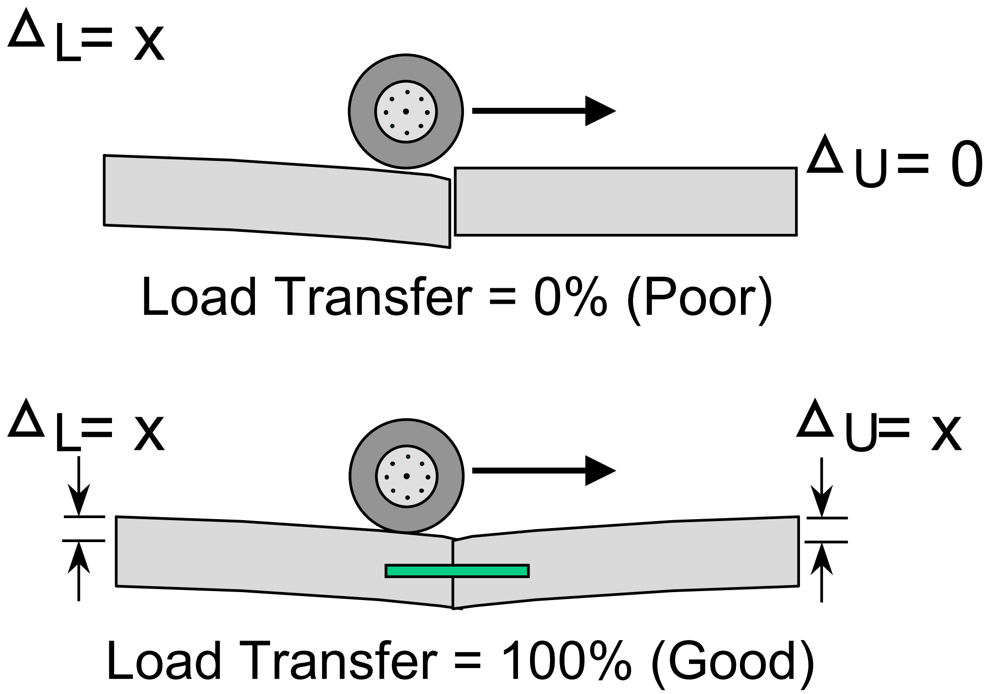


Figure 1: Load Transfer Schematic

transverse slab joints. Load transfer improves concrete pavement performance by reducing the potential for faulting. In addition, deflections are decreased, reducing cracking and in some cases pumping. If the concrete pavement is to be overlaid, the load transfer restoration can reduce the potential for reflective cracks. . Dowel bar retrofitting followed by diamond grinding provides for an extended life and smoother riding surface for existing concrete pavements.

The Department's design standards for dowel bar retrofit are detailed in New Standard Plan (NSP) A35D and corresponding Standard Special Provision 40-015, "Retrofit Existing Concrete Pavement with Dowels at Transverse Joints". The most current versions of these standards should be incorporated into the project PS&E documents. The latest versions of these standards may be obtained by visiting the Engineering Service Center – Office Engineer web site.

IDENTIFYING CANDIDATE PROJECT LOCATIONS

Dowel bar retrofitting is well suited for JPCP that has poor load transfer at the joints and / or mid-panel cracks, but also have significant remaining structural service life. JPCP considered for dowel bar retrofit should have few, if any, joints with deterioration related to poor concrete durability and / or fatigue cracking. A good example of a pavement that is a candidate for dowel bar retrofitting is a pavement with structurally adequate slabs (proper thickness), but a significant loss of load transfer due to poor aggregate interlock, and / or erosion of the base or subbase that has caused the loss of support at the joint. A second example is a relatively new pavement that, because of insufficient slab thickness, excessive joint spacing, and / or inadequate joint load transfer, is at risk of developing faulting, working cracks, and corner breaks unless the joint or crack load transfer is improved.

Pavements that have little remaining structural life, as evidenced by a substantial amount of slab cracking or faulting, are not good candidates for load transfer restoration or other non-overlay restoration techniques. Even if the existing cracking is repaired, additional fatigue cracking will develop relatively soon, and the remaining time before the pavement will require a structural overlay may be so short that load transfer restoration is not a cost-effective rehabilitation option. A recommended rehabilitation strategy for these pavements is slab replacement with dowel bar retrofit in the truck lanes.

Pavements exhibiting D cracking are not good candidates for load transfer restoration because the concrete in the vicinity of the joints and cracks is likely to be weakened and thus retrofit dowels would not have sound concrete to bear against. D cracking occurs when freezing and thawing cycles cause deterioration that resembles the letter D at the joint face. For D cracked pavements with concrete deterioration only in the vicinity of joints and cracks, full-depth repair is more appropriate than load transfer restoration.

Pavements with distress caused by alkali-silica reaction (ASR) are also not good candidates for load transfer restoration. Reactive aggregate distress occurs in pavements in which certain types of siliceous aggregates react with the alkali's in the portland cement, producing a gel product that expands in the presence of water and fractures the cement matrix, eventually producing cracks in the slab. As with D cracking, the concrete in the vicinity of joints and cracks is likely to be weakened and the dowel bar retrofit would not have sound concrete to bear against.

MEASURING LOAD TRANSFER BETWEEN SLABS

A determination of load transfer for a representative number of joints should be made to identify whether or not joints would benefit from dowel retrofit application. Heavy-load deflection devices such as the Falling Weight Deflectometer (FWD) from METS, Office of Structural Section Design & Rehabilitation, should be requested to perform deflection measurements. These FWD deflection measurements simulate truck wheel loading as it travels over the joint. Traffic control is needed when using a FWD. A FWD can test up to 10 slab joints in 60 minutes on an outside lane minus the time needed to set up and take down the lane closure. Interior lanes may require a full lane closure. District Maintenance typically performs lane closures.

Some general condition criteria to determine whether a dowel bar retrofit is warranted include:

- Faulting < 2.5 mm and number of cracked panels ≤ 10%, do nothing.
- Faulting ≥ 2.5 mm and < 12.5 mm and number of panels cracked ≤ 10%, DBR
- Faulting ≥ 12.5 mm, number of panels cracked ≤ 10% & ADT ≤ 50,000, DBR
- Faulting ≥ 12.5 mm, number of panels cracked ≤ 10% & ADT > 50,000, Reconstruction
- Deflection load transfer of 60% or less
- Differential deflection of 250 µm (10 mils) or more.
- Ride Score 20-40; IRI = 150 - 200

It is important to note that poor ride quality is another trigger to consider using DBR.

DESIGN AND MATERIAL CONSIDERATIONS

Dowel bars are either 32mm or 38 mm in diameter. The larger diameter bar is used in thicker pavements (> 215 mm). Dowel bars are spaced 300 mm on center in sets of three or four per wheel path. Edge spacing from the longitudinal joint to the first dowel bar varies for the outside truck lane. This edge distance is dependent on whether tie bars are located at the longitudinal joint. If tie bars are not located at the longitudinal joint at the shoulder, then the edge distance will be reduced to resist the greater stresses that occur along the edge of pavement.

Industry and FHWA recommend the dowel bar retrofit assembly as shown on Standard Plan Sheet, NSP A35D. The smooth dowel bars provide shear load transfer while also permitting horizontal opening and closing of the joint in response to daily and seasonal temperature and moisture fluctuations. The dowels, including the ends, must be protected from corrosion; a factory-applied epoxy coating is specified. All dowels are coated with a bond breaker to keep the grout from adhering to the bar.

The dowels are also fitted with an expansion cap to allow for horizontal movement on the longitudinal axis. Mounting chairs are used to position the dowel in the slot. These chairs elevate the dowel above the bottom of the slot to allow backfill grout material to flow around the dowel. A foam core insert placed in the transverse joint is also needed to re-establish the transverse joint through the backfill material and to prevent the backfill material from flowing into the slot created below the joint saw cut or into the sides of the existing joint. Caulking filler is used as added protection to prevent backfill grout from entering the slot created by the saw cut in the transverse joint. The caulking filler and foam core insert placement are extremely important. If grout enters the joint, then the joint may "lock-up" resulting in cracking or spalling.

Fast setting grout is used for backfill material. The grout material specified will have minimal shrinkage and quick curing properties. Normally, dowels will be used in urban areas where traffic control will restrict the daily construction windows to overnight work. This will require the grout to cure in a 3 or 4 hour time period and limit the contractor's production somewhat due to the mobilization and construction windows set by the contact. In addition, the temperature requirement for placing grout is restricted to pavement temperatures of 5°C or warmer. Longer construction windows and daytime operations will enhance productivity and may reduce unit costs for dowel retrofits.

EFFECTIVE PLACEMENT

Dowels should be placed in lanes where there are truck or bus traffic (HOV/Outside lanes). Three or four dowels should be placed directly beneath truck tire wheel path to support the load transfer between slabs. Four dowels should be used where anticipated future traffic loading is greater than 15,000 AADTT or a Traffic Index of 12. Placing dowels in non-truck lanes is not cost effective considering the lower stresses due to lighter vehicle traffic. If traffic loading is great enough, then retrofitting dowels in non-truck lanes is justifiable. In areas where the lane lines do not coincide with the longitudinal joints, placement of dowels may not be aligned with the wheel path, thus negating the effectiveness of the dowels as a load transfer device. Engineers should consult with Office of State Pavement Design or ESC-METS, Office of Rigid Pavement for advice on dealing with this situation. In all likelihood, placing dowels at 300 mm on center across the transverse joint and perhaps adding tie bars across the longitudinal joint will alleviate this problem. It should be noted that the dowel placement should be parallel to the longitudinal joint without regard to the lane lines.

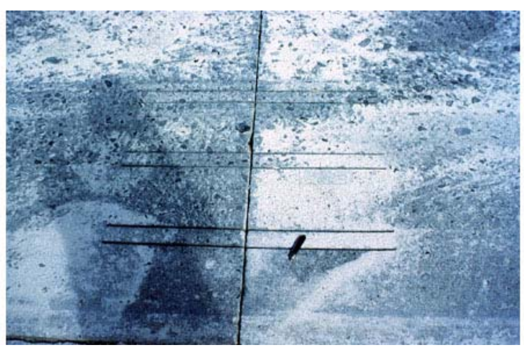
CONSTRUCTION STEPS

Dowel bar retrofitting consists of the following steps:

1. Saw cutting the slots.

Typical Slot Cutting Machine

Diamond Blade Gang Saw



3 Slots Cut in Wheel Path of Slab

Saw cutting is performed by a gang saw that can simultaneously saw 6 or 8 cuts for the 3 or 4 slots. Gang sawing will keep the slots parallel. Single blade saw cutting machines cannot reliably create parallel cuts and therefore, are not allowed. Misaligning the dowels will cause the joint to lock up and subsequent cracking to occur. Saw cuts can be made up to 6 days prior to concrete fin removal. Traffic may be allowed over these saw cuts prior to removal. In many cases, the transverse joint will be skewed. The contractor shall adjust the saw cuts to ensure enough slot is on each side of the transverse joint. Saw cutting should not begin if it is anticipated that the ambient temperature during the dowel placement will fall below 5°C, since grout backfill can only be placed when the pavement temperature is above 5°C.

It is important that the saw cuts are made to the correct depth to place the dowel in the mid-panel depth when the slot material is removed. Saw cuts cut too deep will cause corner cracking after traffic is allowed on the pavement. Corner cracks are cracks that proceed at a 45° angle from the outside slot to the edge of the pavement. The contractor should physically measure an assembled dowel bar with dowel bar chairs attached from the center of the dowel to the bottom of the chair, and then add one half of the pavement depth to determine the proper saw cut depth. This physical measurement should be completed as dowel bar chairs dimensions sometimes vary from that specified.

Slots should be aligned to miss longitudinal cracks. Slots that intersect longitudinal cracks usually fail. The failure mechanism is usually debonding of the backfill material from the sawn joint walls. Shifting the slots 75 to 100 mm in one direction may help alleviate this problem. If the longitudinal crack appears to be a working joint, consider removing this panel versus trying to dowel retrofit it at the transverse joint.

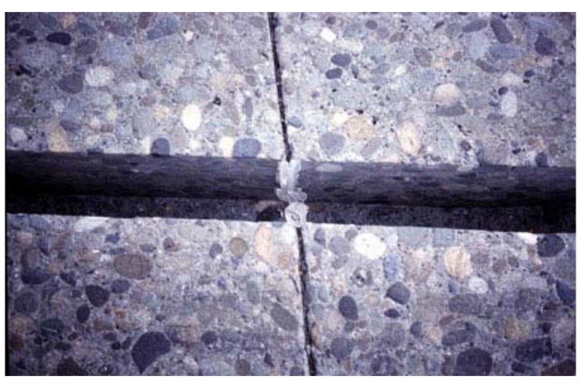
The alignment of the saw cuts must be parallel to the longitudinal joint that may be parallel to the roadway centerline. Dowel bars slots placed perpendicular to skewed joints will cause joint lock up and lead to pavement cracking. As mentioned before, the slots cut on skewed joints should be cut so that equal portions of the slot reside on each side of the transverse joint.

2. Removing the concrete from the slots cut in the pavement.

The concrete fins (concrete in the slots) are to be removed with lightweight pneumatic hammers (not greater than 14kg). Heavier pneumatic hammers can punch through the floor of the slots. Pneumatic hammers should not be used perpendicular to the plane of the pavement. A 45° angle should be used with pneumatic hammers. The bottom of the slot is smoothed and leveled with a small hammerhead. All loose rock and debris is removed. Leveling the bottom of the slot is critical for allowing the dowel bar to rest level to the pavement surface and to allow the grout to flow around the bar to encase it.

3. Cleaning the slots.

Preparing the slots after the concrete fins are removed is essential to good bonding. The slot is to be cleaned by sand blasting, air blasting and vacuuming the slot. No debris or water shall remain in the slot. Residual water in the slots is unacceptable and must be removed entirely. A physical check of the slots cleanliness should be made using a scraper tool to ensure that no slurry residue remains on the slot walls. Sometimes, multiple cleanings are required to remove all debris. Concrete chunks, dirt, debris, and slurry residue shall be cleaned about one meter from the slots perimeter. Without this procedure, deleterious materials can easily be reintroduced into the slots during subsequent operations.



4. Placing silicone sealant in the existing joint.

Once the slot is cleaned, the transverse joint opening at the slot is exposed. The portion of the transverse joint that is exposed by the concrete removed from the slot is to be filled with caulking filler to prevent grout from entering the joint. If grout is allowed to enter the joint it can later inhibit slab expansion and contribute to joint spalling, blowups or compression failure of the joint. Excess caulking filler should be removed. The sealant should not extend 12mm outside of the joint. This surplus sealant will not allow the backfill material to bond to the sides of the slot. It is important that the slot be dry prior to installing the sealant. Sealants will not adhere to wet surfaces.

2. Placing the dowel bar and chair in the slot.

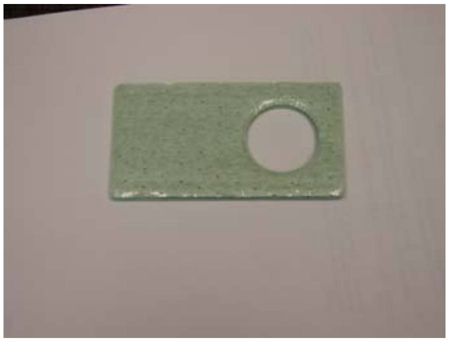
Dowel Bars with End Caps, Chairs, and Foam Core Inserts attached.

Placing Dowel Bars in the Slots.

Dowel Bar and Foam Core Insert both aligned within Slot.

The placement of the dowel bars into the slots occurs after the slot is cleaned and properly prepared. The dowel bar has an epoxy coating to impede corrosion and has a factory applied bond breaker to prevent the grout from adhering to the dowel. The epoxy coated dowel bars must be protected form sunlight and moisture by covering with opaque polyethylene sheeting or other suitable protective material. The epoxy coating shall also be free of nicks and abrasions prior to placement in the slot. The requirements for protection of epoxy coated dowel bars are specified in Section 52-1.02B of the Standard Specification.

The dowel bars are to be fitted with expansion caps at each end, a Styrofoam or fiberboard foam core insert over the middle, and non-metallic support chairs and are normally assembled off-site. Expansion caps are fabricated from a plastic material. The dowel bar and expansion caps allow for temperature expansion of the bar and movement of the slabs. The support chairs will provide a minimum clearance beneath the dowel of 13 mm; which allows the grout backfill to flow around the dowel bar and encase the dowel bar, if the grout is properly consolidated. The chairs are fabricated from a plastic material, and should be placed near each end of the dowel bar.



Foam Core Insert (shown without tabs).

The foam core insert is installed to maintain the existing transverse joint. The foam core insert should be the same width as the final width of the transverse joint. Foam core inserts are usually fabricated from a blue Styrofoam material. Other materials can be used for the form core insert provided that the material is rigid enough to remain in a vertical position when grout is placed. The Caltrans standard plans show tabs on the foam core insert to aid in locating the insert in the transverse joint. Once the dowel bar is prepared, it should be centered across the transverse joint.

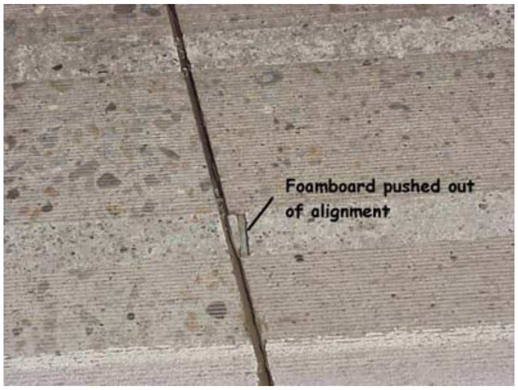
3. Placing grout backfill in the slot.

Placing Grout in the Slots.

Consolidating the Grout in the Slots.

Striking off the Excess Grout.

After the dowel bar assembly is completely in-place, fast setting grout is placed into the slots, and is consolidated with a small spud vibrator. Special care should be taken to ensure that the foam core insert remains in the center of the existing transverse joint. Grout should be placed on either side of the foam core insert in balanced amount to keep the insert upright. Grout should not be dumped onto the slots. Placing the grout on the surface adjacent to the slot and shoving it towards the slot allows the least amount of movement of the foam core insert, and the dowel assembly. If after the grout sets, the foam core is not in alignment with the existing transverse joint, the grout and dowel in the slot is to be removed and replaced with a new dowel bar assembly and backfilled with grout.



The results of poor installation of the Foam Core Insert.

Special care should be taken not to allow the vibrator to touch the dowel. Touching the dowel bar may cause the grout to segregate from the dowel. Care should be taken to not over vibrate the grout, which leads to fines floating to the surface of the slot.

The surface of backfilled dowel bar slots is to be rounded 3 mm above the existing concrete surface, which will be removed during subsequent grinding work. In no case should the grout backfill be allowed to exceed the 3mm above the existing pavement surface. Excess material above the slots will result in poor driving conditions and may contribute to premature cracking of the grout material until the actual grinding has taken place.

The fast setting grout shall be cured by applying curing compound (1) or (2) and should be allowed to cure a minimum of 2 hours after final set. Traffic shall not be allowed over the slots until either compressive strength is greater than 21 MPa or modulus of rupture of 2.4 MPa or greater is achieved.

4. Diamond grinding the slotted JPCP.

Milling is not allowed, as the impact action of the milling machine will damage the concrete pavement surface and transverse joints. The ride quality will be poor until grinding occurs to remove the over-poured grout slots; however, because of construction efficiencies, the lane may be open to traffic prior to grinding. Once the grinding is completed, the pavement will not only ride better, but also it will sustain loads much longer. Grinding should occur within 30 days of slot cutting. The grinding provides a smoother riding surface, the DBR provides the improved load transfer at the transverse joints.

JOINT SEALING

After grinding is completed, existing joint sealant, if any, shall be removed. A new joint reservoir shall be sawn across the dowel bars and transverse joint. The joints shall be thoroughly cleaned, and a new backer rod installed. The backer rod shall be cut and not torn off by pulling. Pulling will deform the backer rod and reduce its effectiveness. Once the backer rod is installed, the silicone sealant should be applied to a clean dry reservoir. No traffic should be allowed on the sealant until it is cured to a sufficient hardness as to not track onto the pavement surface by tires.

DOWEL ALIGNMENT ASSURANCE

Dowels shall be kept in alignment. Core drilling will be required to check for alignment. Dowels shall be within 6 mm per 300mm length tolerance in any direction. Cores should be taken where misalignment is suspected. Misalignment can cause the joint to lock up. Once the joint locks up, a crack or spalling will result at that joint.

Dowel Bar properly installed and crack developed at the joint.

RESIDENT ENGINEER'S GUIDANCE DURING CONSTRUCTION

Separate technical guidelines are available for use during construction relating to materials approval, construction inspection and quality, and contract administration. In general, however, the Resident Engineer (RE) should inspect each product to determine if it meets the specification requirements.

- Dowel bars shall be adequately coated with epoxy and bond breaker.
- Dowel bars slots are to be cleaned. Insufficient cleaned slots will result in poor grout adherence to the slot walls.
- The sawcut depth is sufficient to place the dowel in the center of the pavement.
- Support chairs shall only allow 13 mm clearance in beneath the chairs. Larger chairs will reduce clearance and misalign dowel bars.
- Expansion caps should fit snuggly on each end of the dowel.
- Caulking filler is the first line of protection to keep grout from entering the transverse joint.
- The foam core insert thickness shall be same as the joint width. The foam core insert keeps the grout from entering the transverse joint and maintains the joint.
- Fast setting grout is approved for use prior to construction.
- Fast setting grout shall be in accordance with the special provisions, and should cure in two to three hours. The grout shall never be retempered with water.
- The grout after placement shall not be more than 3 mm above the existing pavement surface. Excessive grout will crack after traffic is allow back on the road and grinding does not occur within the specified time interval.
- Coring is used to determine dowel bar alignment. A core should be taken at each end of the bar. By coring at the end, the bar is shortened, but not totally damaged so that it will still provide some load transfer.

OTHER TOPICS OF INTEREST

USE OF DOWEL BAR BASKETS WHEN MULTIPLE ADJOINING SLABS ARE TO BE REPLACED WITHIN THE SAME LANE

Occasionally, Designers or Contractors have requested to use dowels with dowel bar baskets in the transverse joints of adjacent slabs, which are to be replaced in the same lane. Dowel bar baskets are not a retrofit strategy, but a new PCC design feature (Refer to Standard Plan A35B). If this is to be done, it is important that the dowel baskets ordered match the existing joint's skew configuration (either skewed or perpendicular). Using dowels with dowel baskets will work, but the Designer / Contractor should avoid intermixing dowel bar retrofit with regular dowel bar installation. Unless there are a significant number of locations where multiple adjacent slabs within the same lane are to be replaced within one project, construction contract administration can be complex and unit costs can be expensive. When using dowel baskets, the dowels are to be spaced at regular intervals as shown on the standard plan for new transverse joint locations (i.e. 12 dowels per lane width). If dowel bars with dowel baskets are to be used, then the appropriate SSP and details from the Standard Plan need to be included in the project plans and specifications, along with plan sheets showing the specific locations where dowel bar baskets are to be placed. The appropriate bid items will also need to be added to the Engineer's estimate for the project.

PERFORMANCE

Generally speaking, dowel bar retrofits have performed well in other States. Puerto Rico, Georgia, Washington and Minnesota are some of the States and / or Commonwealths that have used dowel retrofit successfully. In some locations, concrete slabs that have been dowel bar retrofitted have been in service and have performed well for 15 years under traffic.

There are some on-going studies to determine if 3 dowels per wheel path is adequate for all loading conditions.

COSTS

Costs vary from project to project; however, the average range cost has ranged from $30 to $45 per dowel for routine installations. It is anticipated that as dowel bar retrofitting becomes more commonplace in California and improvements in equipment become available to increase productivity, unit costs will decrease. Please check the latest costs from the Contract Cost Data Base found on the Office Engineer's website.

Washington State DOT estimates that the cost for load transfer retrofitting is $40,000 less per km of 2-lane roadway than a conventional 90-mm asphalt overlay and will last 10 to 15 years. Their estimate includes slab replacement, load transfer restoration in the truck lane, diamond grinding, and joint and crack sealing.

Credits:

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